Computerized Energy Analysis for the Mars Operations Support Building

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This article describes a detailed computerized building load simulation of the Operations Support Building at the Mars Deep Space Station, Goldstone, California. Five energy conservation suggestions were investigated prior to implementation. The results showed that cost savings of about 16 percent of present energy costs are possible.

I. Introduction

Energy conservation in the JPL-managed deep space tracking facilities continues to be a major concern in the face of unpredictable and scarce fossil fuel supplies. Energy needed for heating and cooling is increasingly expensive and in short supply. However, heating, ventilating and air conditioning (HVAC) systems are continuously changed by optimizing equipment size and performance and upgrading controls to keep energy consumption at the lowest level.

The Operations Support Building (G-86) at the Mars deep space tracking facility at Goldstone, California, is one of the buildings which has a significant energy consumption. A study was initiated to give a detailed building load analysis, to identify the major energy consumption areas and to investigate the economic benefits of implementing several suggested energy conservation measures. This study is based on the latest building operating mode (BOM) and makes use of an in-house computerized energy consumption program (ECP). The results are described below.

II. Building Configuration

A. Building Description

The Operations Support Building is a two-story building with 1,271 m² (13,680 ft²) total floor area. Figures 1 and 2 illustrate the floor plan for each story. The building is actually composed of 7 air-conditioned zones which are grouped for convenience and modeled by ECP as 6 macrozones. Table 1 lists the location, the conditioned air flow rate to each zone and the number assigned to each zone.

Figure 3 is a sketch of the present HVAC system configuration for the building. The building is air conditioned by three active air handlers (AH1, AH2, and AH3) and a standby unit (AH4). Presently, the heating coils of air handler AH1 are connected to an electric resistance boiler. The coil modulates the air temperature for zone 1 (offices) and zone 3 (control and communication rooms) only.

In the model, the second floor offices are divided into two zones (zones 1 and 4) as indicated in Table 1. Also the com-

mon plenum for both communication and the control rooms is modeled as zone 2 and the comfort area of the communications room as zone 3. The restroom (room 205) is treated as zone 5, and the hydrogen-maser room is identified as zone 6. The first zone receives a total of 3,993 m³/hr (2,350 cfm) from airhandler No. 1 (AH1). The plenum (zone 2) receives a total of 67,968 m³/hr (40,000 cfm) of cold air from two air handlers: 28,886.4 m³/hr (17,000 cfm) from AH1 and 39,081.6 m³/hr (23,000 cfm) from AH2. The third zone receives a total of 11,010.8 m³/hr (6,480 cfm) from AH1. The remaining offices (zone 4) and the restroom receive 679.7 m³/hr (400 cfm) and 212.4 m³/hr (125 cfm) for AH1, respectively. The maser room is supplied with 3,398.4 m³/hr (2,000 cfm) from AH3.

The office and the restroom (zones 1, 4, and 5) are modeled as simple zones. The maser room is also treated as a simple zone and is supplied by a separate air handler (AH3) which utilizes the cold air in the plenum for the supply air. A small condensing unit connected to AH3 will operate only when the plenum air temperature is above the AH3 cold deck setpoint. The control room and the comfort area, which are both cooled by the plenum's cold air, are combined into zone 3. Cold air is fed to the plenum and passes through and cools the electronic racks located on the upper level.

B. Structural Data

The structural data of the roof, wall and floor layers for each zone are taken from drawing specifications and field inspection for computing the following heat transmission properties: the overall heat transfer coefficient at steady state U, the amplitude of the heat transfer coefficient for periodic (transient) heat transfer V, and the phase angle (thermal lag) ϕ. Table 2 lists the computed U, V, ϕ values for each zone.

C. Internal Loads

The building internal loads include lighting loads, electrical and mechanical equipment loads, occupancy and thermal loads. The data are taken from current field survey, operating procedure, and equipment specifications.

D. Primary Equipment Data

Air handler AH1, feeding zones 1, 2, 3, 4, and 5, is a multizone air handler with double ducts and terminal air mixing boxes. Air handlers AH2 and AH3 are both single-zone air handlers providing cold air only. Zones 2 and 6 are fed by air handlers AH2 and AH3, respectively. The setpoints for AH1 are set at 11.1°C (52°F) for the cold deck and 22.7°C (73°F) for the hot deck. A single setting of 16.7°C (62°F) is assumed for air handler AH2. The setpoint of AH3 is 20.5°C (69°C). There is no outside air economizer on any air handler. The

outside air ventilation ratios for AH1 and AH2 are both selected to be 0.05 and AH3 is set at 0.01.

Presently, there are three parallel vapor compression chillers at 98.45 kW(t) (28 tons of refrigeration), each connected to air handler AH2. Two of the chillers are operating and the third is a standby unit. The two parallel chillers were lumped into C1 as a four-stage unit with 49.24 kW(t)/stage (14 tons/stage) capacity. Air handler AH2 is connected to a chiller C2 modeled as a three-stage unit at 49.24 kW(t)/stage (14 tons/stage) capacity. A smaller single-stage unit, C3, is connected to air handler AH3 with 17.58 kW(t) (5 tons) capacity.

III. Result of Analysis at Present Operating Conditions

The result of the computerized analysis of building G-86 indicates that the building at current operating conditions consumes 1,856.9 MWh(e) annually. The annual energy cost is about $112,776 based on the Southern California Edison electric energy cost rate as shown in Fig. 4. Table 3 presents the itemized annual energy consumption of the building. Forty percent of the total energy consumed by the building is due to electrical and electronics equipment such as computers and spacecraft tracking control equipment. Cooling equipment consumes the second largest portion of the total annual energy needs.

The peak cooling loads for chillers C1, C2, and C3 are 142.08, 86.16, and 17.58 kW(t) (40.4, 24.5 and 5 tons of refrigeration), respectively. Hence, the total installed capacity of each of the three chillers is adequate to provide the peak load. The peak annual heating load for heater H1 is given as 2.37 kW(t) (or 8,105 Btu/hr), which if compared to the heater capacity of 60 kW(t) (205,000 Btu/hr) means that the heating demand can be well satisfied.

The computerized model also indicates that the present air flow for zone 1, 13,993 m³/hr (2,350 cfm), is less than the calculated design air rate of 5,233 m³/hr (3,080 cfm), which causes the temperature fluctuation in zone 1 during the summer months. However, the present cold draft from the open door connected to zone 3 makes up for the deficiency of air flow in zone 1. Combined air flow rate for zones 2 and 3 is presently 78,979 m³/hr (46,480 cfm), which is lower than the design rate or 85,884 m³/hr (50,544 cfm). This difference in air flow rate also results in temperature fluctuations of zones 2 and 3. The present air flow rate for the remaining zones is higher than the computerized design values and is considered adequate.

The required supply air temperature for air handler AH1 was analyzed and was found to range from 10°C (50°F) to

28°C (83°F), which is beyond the setpoints limits of 11.1°C (52°F) to 22.8°C (73°F). However, the difference in supply air temperature can be corrected by increasing the air flow of AH1. The setpoints on air handlers AH2 and AH3 match the required supply air temperature within 1°C(~2°F).

IV. Proposed Modifications

Since the cooling energy represents 25 percent (454,600 kWh(e)) of the total building energy consumption, several suggestions have been made to modify the existing HVAC system to improve performance and reduce energy consumption. The modifications described next are superimposed; i.e., whenever a modification is simulated and found to yield significant energy savings, it is retained as a new base for the next one and so on. Each suggestion was analyzed and the results are presented below.

A. First Modification: Change the Inside Design Temperature to 20°C–25.6°C (68°F–78°F) Range; Install "Dead Band" Thermostat Controls

This modification proposes to change the inside temperature from 22.2°C (72°F) all year round to a variable temperature ranging from a maximum 25.6°C (78°F) to the minimum 20°C (68°F) for zones 1, 4, and 5. For zone 2 (the plenum) the design temperature remains at 17.8°C (64°F). The control room, zone 3, remains at 22.2°C (72°F) all year round.

The annual consumption of the building, after modeling this modification, has dropped to 1,851.7 MWh(e) from the present 1,856.9 MWh(e), resulting in a $310 savings. The annual heating energy has reduced also from 3,784 kWh(e) to 349.5 kWh(e). The peak heating load for heater H1 has dropped by 69 percent from the present condition.

B. Second Modification: Add a Variable Air Volume (VAV) Control for Zone 3 Only

This modification provides a VAV control to zone 3 by installing a motorized damper, the hot duct, closing off the cold duct and bypassing the supply air at unit AH1 whenever there is a decrease of air at zone 3.

The computer results indicated that the total annual consumption dropped from 1,851.7 MWh(e) to 1,849.9 MWh(e), which resulted in a saving of $118 annually. The heating and cooling consumptions are 349.5 kWe(e) and 451.4 MWh(e), respectively. If this modification had been made on the plenum, i.e., installing motorized dampers on the computer racks to regulate warm air flowing into the control room, the saving would have increased. However, the final choice will be made in the final design stage.

C. Third Modification: Rearrange the HVAC System and Change the Piping Network to a Chilled Water System

In this modification, air flows from AH1 to zones 1, 2, and 3 are adjusted to the new flow rates, 5,097.6, 33,984, and 5,904 m³/hr (3,000, 20,000 and 3,475 cfm), respectively. Compressor C1 is modified to feed both AH1 and AH2. Chiller C2 is disconnected from AH2 and turned off. The air flow of AH2 is reduced from 39,091.6 m³/hr (23,000 cfm) to 33,984 m³/hr (20,000 cfm). The piping network will be changed to a chilled water system with the addition of a liquid cooler (LCI).

With this modification, ECP indicated a decrease in energy consumption from 1,850 MWh(e) to 1,757.3 MWh(e) and a decrease in energy cost from $112,348 to $106,740. The cooling energy has decreased from 451.4 MWh(e) to 427.4 MWh(e), and the heating energy has decreased from 0.350 MWh(e) to 0.065 MWh(e). Due to the new air flow, the maximum cooling on chiller C1 has increased to 321 kW(t) (65.7 tons) from the combined C1 and C2 in the previous modification. Also, the peak heating load was reduced significantly to 0.3 kW(t) from 0.8 kW(t) in the previous modification.

D. Fourth Modification: Add Economizer and Automatic Temperature Reset Setpoints to Air Handlers AH2 and AH3

This modification proposes to add economizer and automatic hot and cold deck reset controls to both air handlers AH2 and AH3. Figure 5 illustrates the modified HVAC system configuration with operating economizer for units AH2 and AH3. When the economizer is not in operation, Fig. 6 represents the modified HVAC configuration for that particular situation.

Annual energy consumption has been reduced to 1,604.0 MWh(e) due to the lower cooling energy required (228.0 MWh(e) vs 427.4 MWh(e)). Energy cost was $97,434, a $9,306 saving over the last modification.

E. Fifth Modification: Add a Chilled Water Storage Tank

This modification proposes to install a chilled water tank for load leveling and to minimize the energy waste of the compressor when running at partial loads. A separate computer program (STORAGE) has been developed to estimate the savings. The tank volume was selected to be 37.85 m³ (10,000 gal) after several size optimization runs.

The computer program (STORAGE) simulates two compressors with each having four stages. Each compressor has a total cooling capacity of 98.5 kW(t) (28 tons of refrigeration)

and each stage represents 25 percent of the total cooling capacity. The minimum cooling capacity of both compressors was assumed to be 0.4 of full capacity. When the compressors are operated in conjunction with the chilled water storage tank, the minimum charging capacity is taken to be 98.5 kW(t) (28 tons) (one compressor capacity). The surplus of the total cooling demand is stored in a chilled water storage tank to be used later in the day. In this model, all losses are neglected. The operating temperature difference of the storage tank is assumed to be 5.6°C (10°F).

Note that the estimated energy and cost savings vary with different modes of operation of the compressor/storage tank system. The projected saving will be about 5.3 MWh(e) or about $2,271.

V. Summary of Modifications

Table 4 summarizes the results of all proposed modifications and the estimated implementation costs. Note that these modifications will not cause any discomfort inside the building because the design conditions are always satisfied. After all the modifications are implemented, the saving will be $17,613, or about 16% of present costs, with a simple payback of 10.5 years.

Table 1. Zone identification for the Operations Support Building

Zone	Zone description	Floor	Zone air flow, M^3/hr (ft^3/min)		ECP Zone
1	Plenum	1	67,968	(40,000)	2
2	Control room, comfort	2	9311.6	(5,480)	3
3	Communication room, comfort	2	1,699.2	(1,000)	3
4	Offices 206, 207, 208, 209, and corridor 202, restrooms 203 and 204	2	3,993	(2,350)	1
5	Offices 210, 211, 212	2	679.7	(400)	4
5	Maser room	1	3,398.4	(2,000)	6
7	Restroom 205	2	212.4	(125)	5

Table 2. Heat transmission properties of the Operations Support Building

Macro-zone	Heat transfer coefficient U, W/m^2°C (Btu/hr-ft^2-°F)			Amplitude of heat transfer coefficient V, W/m^2°C, Btu/hr-ft^2-°F			Phase angle, ϕ radians		
	Roof	Wall	Floor	Roof	Wall	Floor	Roof	Wall	Floor
1	0.3877 (0.0683)	0.4382 (0.0772)	2.2707 (0.4000)	0.2520 (0.0444)	0.1113 (0.0196)	2.8384 (0.5000)	1.5844	2.9081	0.3000
2	3.7251 (0.6562)	0.4382 (0.0772)	2.6357 (0.4643)	3.7206 (0.6554)	0.1113 (0.0196)	0.9372 (0.1651)	0.0575	2.9081	1.9946
3	0.3877 (0.0683)	0.4382 (0.0772)	3.7251 (0.6562)	0.2520 (0.0444)	0.1113 (0.0196)	3.7206 (0.6554)	1.5844	2.9081	0.0575
4	0.3877 (0.0683)	0.4382 (0.0772)	2.2707 (0.4000)	0.2520 (0.0444)	0.1113 (0.0196)	2,8384 (0.5000)	1,5844	2.9081	0.3000
5	0.3877 (0.0683)	0.4382 (0.0772)	2.2707 (0.4000)	0.2520 (0.0444)	0.1113 (0.0196)	2.8384 (0.5000)	1.5844	2.9081	0.3000
6	3.7251 (0.6562)	0.4382 (0.0772)	2.6357 (0.4643)	3.7206 (0.6554)	0.1113 (0.0196)	0.9372 (0.1651)	0.0575	2.9081	1.9946

Table 3. Present consumption itemization[a]

Items	Annual consumption, kWh(e), ECP (1980)	Percent of total
Fluorescent lighting	210,900	11
Incandescent lighting	365	0
Cooling equipment	454,600	25
Heating equipment	3,784	0
Electrical/electronics (non HVAC)	749,000	40
Accessories	438,300	24
Total	1,856,949	100

[a]Rounded figures

Table 4. Summary of modifications for the Operations Support Building based on present conditions

| Run no.	Modification no.	Description	Annual energy consumption, electrical, MWh(e)	Estimated construction costs, $	Annual costs, $	Annual cost savings, $	Payback period, years
1	–	Present conditions	1856.9	–	112,776	–	–
2	1	Addition of dead band controls	1851.7	2,000	112,466	310	6.45
3	2	Addition of VAV control to zone 3	1849.9	1,500	112,348	118	12.70
4	3	Rearranging HVAC system; addition of CHW system	1757.3	80,000	106,740	5,608	14.30
5	4	Addition of HVAC status panel and ECON and auto reset for AH2 and AH3	1600.6	77,500	97,434	9,306	8.30
	5	Addition of chilled water storage tank	1555.3	25,000	95,163	2,271	11.00
All modifications			1555.3	186,000	95,163	17,613	10.50
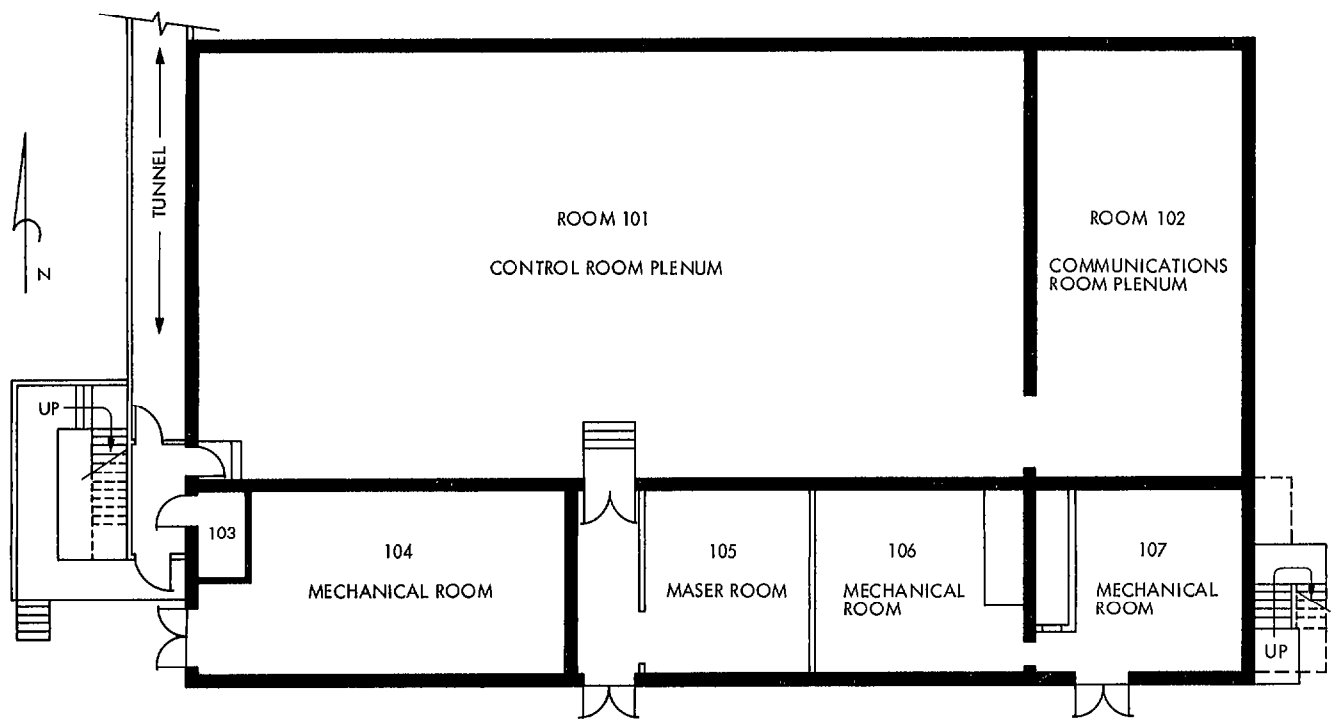
Fig. 1. Floor plan of Operations Support Building (first floor)
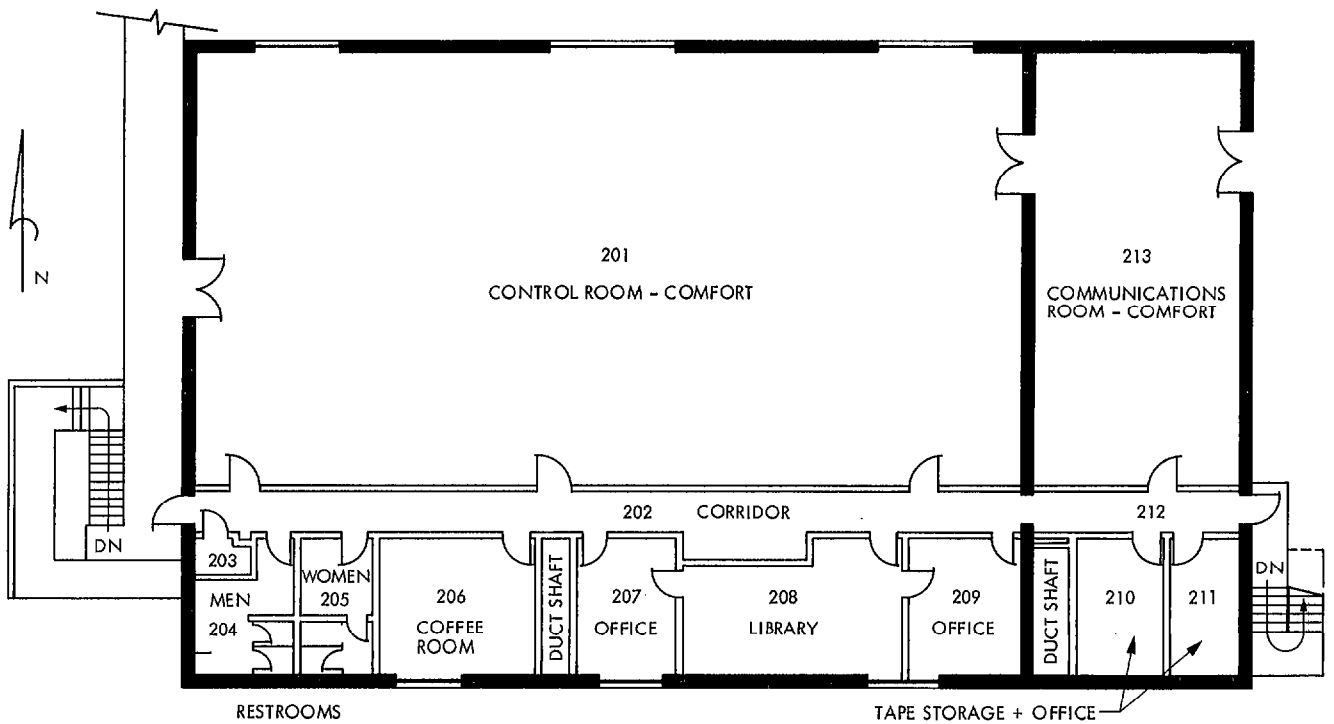
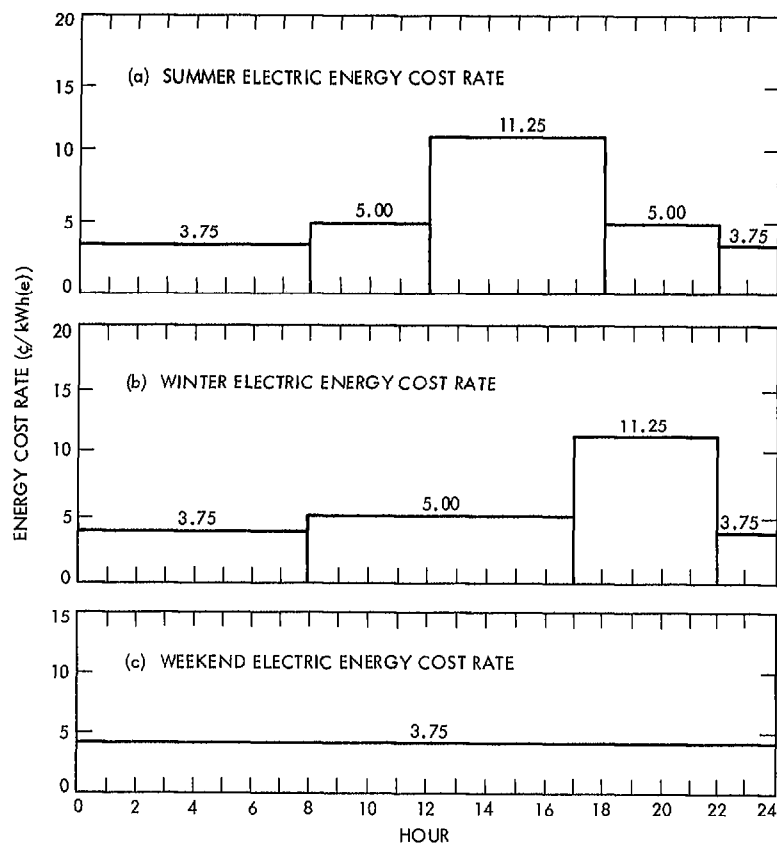**Fig. 2. Floor plan of Operations Support Building (second floor)**
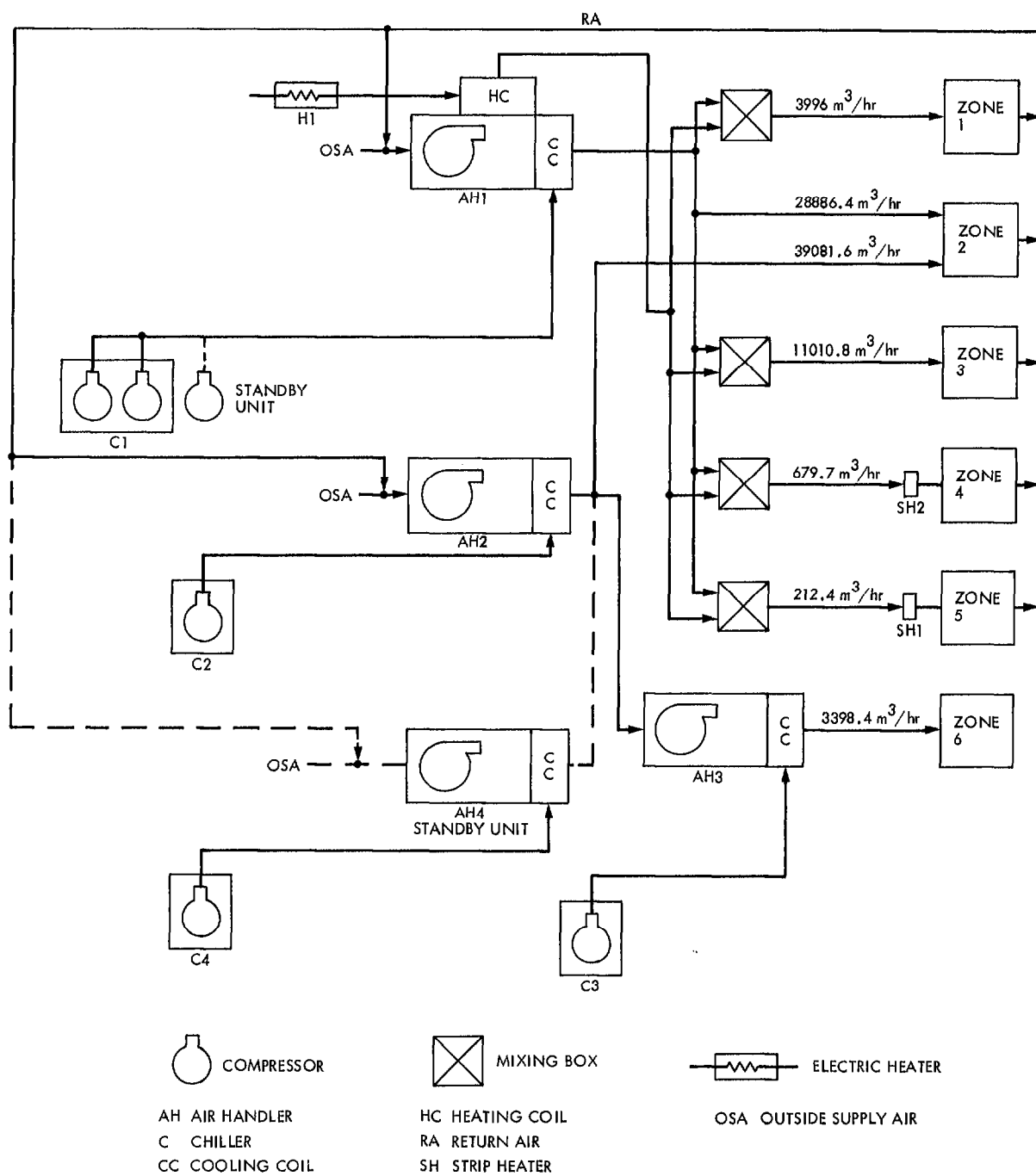
Fig. 3. Present HVAC configuration for the Operations Support Building

Fig. 4. SCE electric energy cost rates

NOTES:
RATES SHOWN IN ABOVE SCHEDULE ARE FROM TOU-8/GENERAL SERVICE-LARGE, SOUTHERN CALIFORNIA EDISON COMPANY DATED JULY 22, 1979, AND INCLUDE A 25% ESCALATION INCREASE, EFFECTIVE OCTOBER 1979

COMPRESSOR   MIXING BOX   ELECTRIC HEATER

AH AIR HANDLER   H   HEATER   LC LIQUID CHILLER
C   CHILLER   HC   HEATING COIL   RA RETURN AIR
CC COOLING COIL   OSA OUTSIDE SUPPLY AIR SH STRIP HEATER

NOTES: (a) STANDBY UNITS ARE NOT COMPUTER MODELED
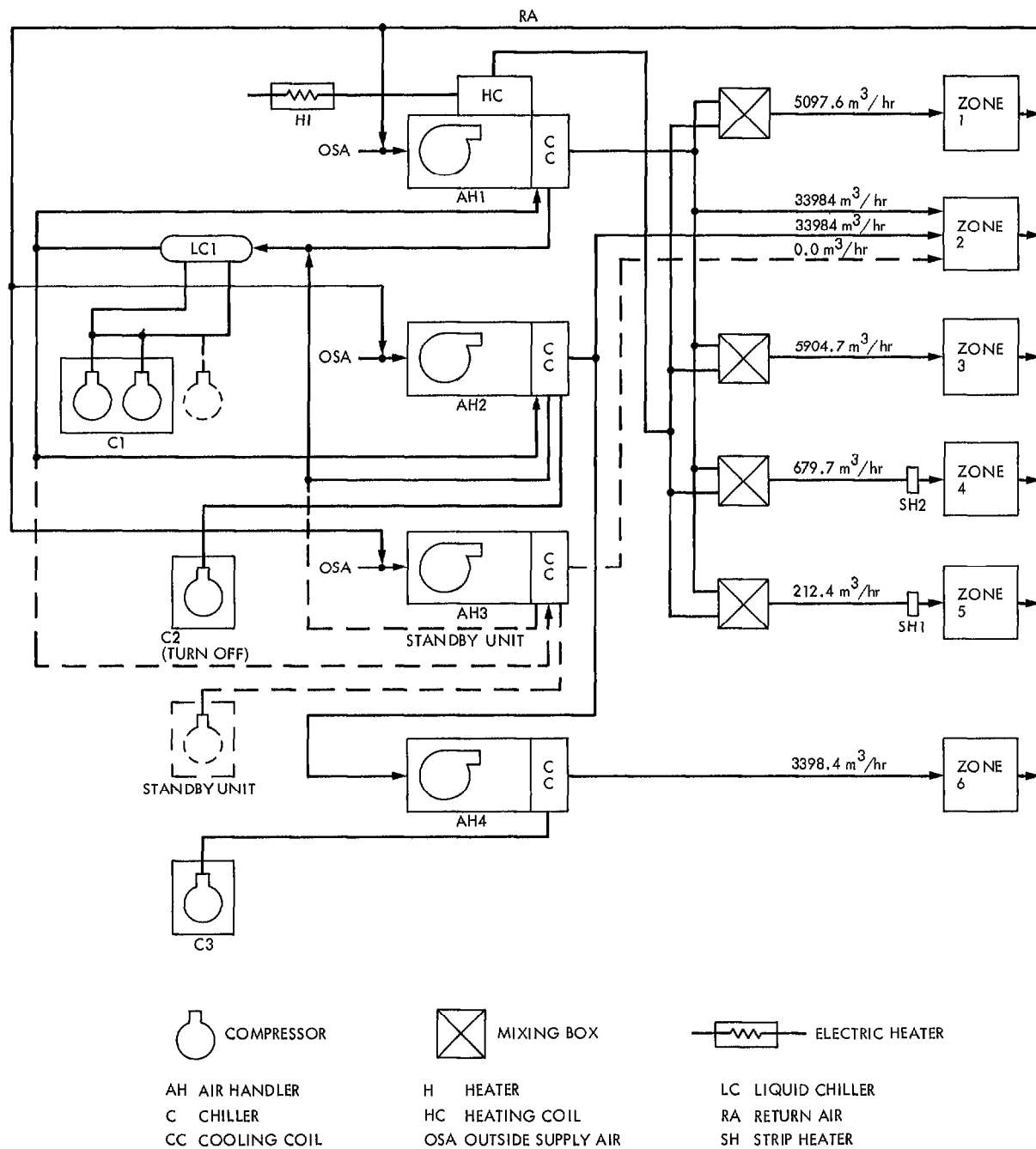   (b) STRIP HEATER SH1 AND SH2 ARE NOT MODELED
         (c) ZONE 7 (NO LOAD) WAS INTRODUCED IN THE COMPUTER MODEL
             AS REQUIREMENT FOR UNIT AH1 TO OPERATE IN STABLE PART
             OF THE FAN CURVE (18691.2 m^3/hr MINIMUM)

Fig. 5. Modified HVAC configuration with operating economizer for units AH1 and AH2

COMPRESSOR   MIXING BOX   ELECTRIC HEATER

AH   AIR HANDLER   H   HEATER   LC   LIQUID CHILLER
C   CHILLER   HC   HEATING COIL   RA   RETURN AIR
CC   COOLING COIL   OSA   OUTSIDE SUPPLY AIR   SH   STRIP HEATER

NOTES: (a) STANDBY UNITS ARE NOT COMPUTER MODELED
            (b) STRIP HEATER SH1 AND SH2 ARE NOT MODELED

Fig. 6. Modified HVAC configuration with nonoperating economizer for units AH2 and AH3